S282 Astronomy

A delicate balancing act

Study time: 20 minutes

Summary

In this activity you will view a video sequence that describes hydrostatic equilibrium; how pressure gradients support stars against gravity. The first part of the sequence discusses the forces due to gas pressure and radiation pressure that provide the pressure gradient to support 'normal' stars. In the second part of the sequence degenerate matter, which supports highly evolved stars, is explained.

The first part of this sequence (up to 4:35) is best watched after you have read to the end of Chapter 6 of *An Introduction to the Sun and Stars*. The second part (4:35 onwards) should be watched after you have been briefly introduced to degenerate matter in Section 7.2.4 of the book. The evolved stars in which it dominates are described in detail in Chapter 9. You may wish to watch this sequence again when you have completed Chapter 9.

Learning outcomes

- Understand the concept of hydrostatic equilibrium as a balance between the force of gravity and a pressure gradient.
- Recognize that in 'normal' stars this pressure gradient may be maintained by gas pressure or radiation pressure.
- Appreciate that the pressure gradient which supports some stars is provided by degeneracy pressure.

The activity

- Open the S282 Multimedia guide and then click on A delicate balancing act under the 'Stars' folder in the left-hand panel.
- Press the Start button to start the video sequence.
- After viewing the first segment (up to time 4:35) the screen will go blank. Pause the player and answer the following question.

Question 1

Try to summarize the argument so far in a few sentences.

You can now watch the second segment or wait until you have read to the end of Section 7.2 of *An Introduction to the Sun and Stars*. In this segment the concept of degeneracy pressure is introduced.

Notes

The video sequence can be summarized as follows (the timings are those that appear on screen as the topics begin).

00:00 Demonstrations and animations illustrate how pressure gradients support stars against gravity and how pressure (due to particles' motion) and temperature gradients are interrelated.

03:50 Radiation pressure is introduced.

04:35 The pause in the tape for Question 1.

04:50 Degeneracy pressure is introduced. Here is a summary of the main points regarding degeneracy pressure:

- Degeneracy pressure is commonly found in some of the late stages of stellar evolution – in white dwarfs and neutron stars.
- Degeneracy pressure is a quantum phenomenon; it is not noticeable in everyday life, but is very important in some extreme physical conditions.
- Quantum effects prevent two (or more) identical particles having the same energy. However, two particles of the same type but with opposite spins may have the same energy. (An analogy of two particles of the same type but opposite spin is a pair of gloves – the gloves are identical except that one is left-handed and the other right-handed.)
- This quantum restriction was demonstrated in the sequence by balls of two different colours. At most, one ball of each colour could occupy the same pigeon hole. This meant some balls were forced up into the higher levels.
- In white dwarfs and neutron stars, degeneracy pressure predominates. As a consequence, pressure is not proportional to temperature: it is far *less* sensitive to temperature than in a non-degenerate star.

07:30 Sequence ends.

Video credits

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Producer – Cameron Balbirnie (BBC)

Course Team consultant – Alan Cooper

Answer to Question 1

Your synopsis should contain the following points:

- Pressure difference across a small element of a star opposes the gravitational force on the material in that element (more precisely, pressure force = pressure difference × area of element).
- The pressure may be due to collisions of gas particles with gas particles or may be due to photons colliding with gas particles. Both types of process occur in all normal stars, but particle collisions dominate if the star's mass is under $5M_{\odot}$ and photon collisions dominate above this.

  In a normal star, gas pressure is proportional to temperature (more completely, pressure is proportional to density × temperature; see *An Introduction to the Sun and Stars*, Equations 6.1 and 6.12). Radiation (photon) pressure is even more sensitive to temperature (Equation 6.11).